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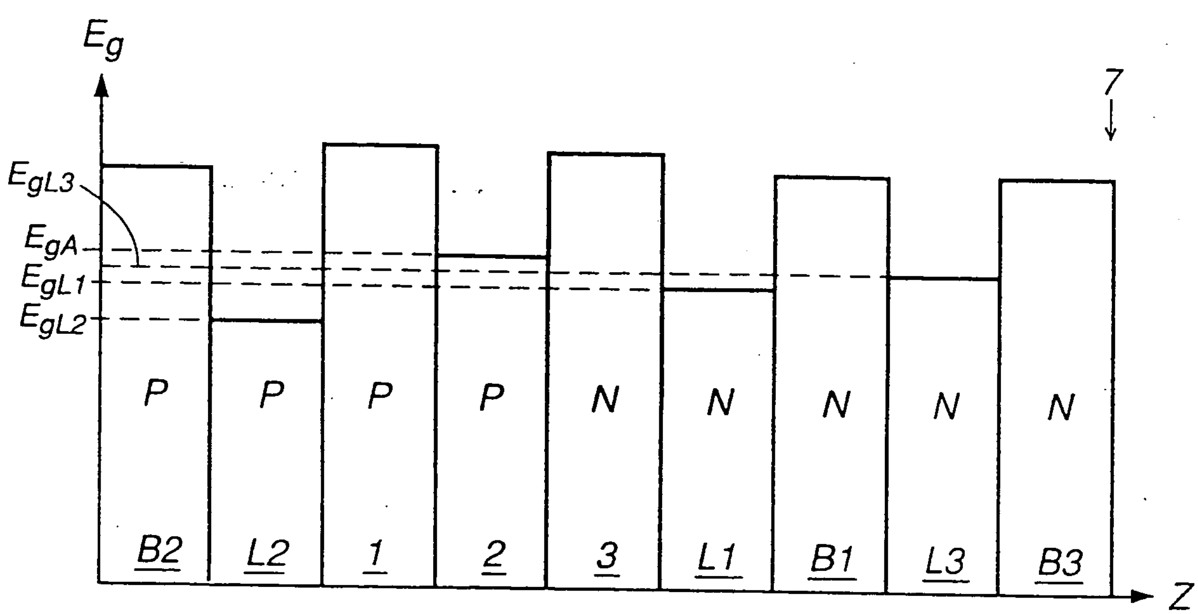
(54) Title: SURFACE EMITTING LIGHT EMITTING DIODE



(57) Abstract

A surface emitting LED has a PN junction (6) between two semiconductor layers (2, 3), at least one layer (2) being an active layer. The diode is adapted for emitting light through an exit surface (7). Between the active layer (2) and the exit surface (7) the diode has a luminescence layer (L1) with a lower energy gap than that of the active layer.

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Surface emitting light emitting diode

TECHNICAL FIELD

The present invention relates to a surface emitting light emitting diode (LED) with a PN junction between two semi-conductor layers, of which at least one is active, the diode being adapted to emit light through a predetermined exit surface.

BACKGROUND ART

By a surface emitting LED is meant an LED which is designed such that at least the main part of the emitted light is emitted from the diode through an exit surface which is substantially parallel to the PN junctions of the diode. By the concept LED is meant a semiconductor device with an active layer adjoining a PN junction. When current is conducted through the diode, charge carriers are injected into the active layer, and upon recombination of the charge carriers, light is emitted. The wavelength of the emitted light is determined by the energy gap of the material in the active layer, and the wavelength is inversely proportional to this energy gap.

Figure 1a shows an example of an LED of the above kind. The material therein may, for example, be GaAlAs. The semi-conductor body comprises four layers 1-4. The layers 1 and 2 are P-doped and the layers 3 and 4 N-doped. In the layers 1 and 3 the material has a higher energy gap than in the layer 2. The layer 2 constitutes the active layer of the diode. The energy gap of the material may be controlled by variation of the aluminium content of the material. A PN junction 6 is formed between the layers 2 and 3. The layer 1 is provided with a contact 5a and the layer 4 with an annular contact 5b for supply of current to the diode. The layer 4 has a centrally arranged well which extends down to the exit surface 7. When current traverses the PN junction, charge carriers are injected, which substantially recombine

in the active layer 2, whereby light is emitted. The main part of the light is emitted through the exit surface 7, and the emitted light is in Figure 1a symbolically shown with the aid of the arrow designated $h\nu$.

Figure 1b illustrates the energy gap E_g for the layers 1-3 as a function of z, where z is the distance along the normal direction to the exit surface 7. The layers 1 and 3 have the equally large energy gaps E_{g1} and E_{g3}, respectively, which are greater than the energy gap E_{gA} of the active layer 2.

The layer 1 may, for example, have the thickness 2 µm, the layer 2 the thickness 2 µm, and the layer 3 the thickness 10 µm.

Figure 1c shows the intensity P_λ of the emitted light as a function of its wavelength λ. The intensity maximum occurs at the wavelength λ_p. The spectral line width of the LED, that is, the half-width of the intensity curve shown in Figure 1c, in a typical LED of the described kind is relatively small, typically about 50 nm.

In certain applications, for example during simultaneous supply of several receivers at separate wavelengths (wavelength-divided multiplex), the low line width of prior art LEDs has proved to be a considerable drawback.

SUMMARY OF THE INVENTION

The present invention relates to an LED of the kind described in the introductory part of the specification. The invention aims to achieve, in a simple and advantageous manner, an increase of the spectral line width of such an LED.

What characterizes an LED according to the invention will be clear from the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be described with reference to the accompanying Figures 1-8. Figure 1a shows a section through a prior art LED of the kind described above. Figure 1b shows the energy gaps for the different layers of the diode. Figure 1c shows the intensity of the light emitted from the diode as a function of the wavelength. Figur 2a shows the energy gaps of the different layers in an LED according to the invention, in which a luminescence layer is provided between the active layer and the exit surface of the diode. Figure 2b shows the light intensity as a function of the wavelength for the diode shown in Figure 2a. Figure 3a shows an alternative embodiment of a diode according to the invention, in which two luminescence layers are arranged on both sides of the active layer. Figure 3b shows the intensity of the emitted light as a function of the wavelength for the diode shown in Figure 3a. Figure 4 shows an additional embodiment of a diode according to the invention, in which blocking layers have been provided adjacent to the luminescence layers. Figure 5 shows an additional embodiment of the invention, in which a luminescence layer has been arranged adjacent to an LED with a so-called simple heterostructure. Figure 6 shows an additional embodiment of the invention, in which a luminescence layer has been arranged adjacent to an LED with a so-called homostructure. Figure 7 shows an LED according to the invention with three luminescence layers. Figure 8 shows a section through an LED according to Figure 7.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 2a shows an LED according to the invention. The diode is composed in the same manner as the diode shown in Figure 1, that is, it consists of a double heterostructure with two layers 1 and 3 with higher energy gaps arranged on both sides of an active layer 2 with a lower energy gap. Between the layer 3 and the exit surface 7, an additional

layer L - a so-called luminescence layer - is arranged according to the invention. The material in this layer has a lower energy gap, E_{gL}, than the energy gap E_{gA} in the active layer 2. In the same way as the layer 3, the layer L is N-doped. When the diode is traversed by current, light is emitted from the active layer 2. This light is partially absorbed and excites charge carriers in the layer L. These charge carriers recombine and thus emit light, which has a wavelength λ_L which is determined by the energy gap E_{gL} of the material in the layer L. The wavelength λ_L of the light emitted from the layer L differs from the wavelength λ_A of the light emitted from the layer 2. By a suitable choice of the energy gaps of the two layers, the intensity curves for the light from the two layers may be caused to overlap in such a way that the total intensity of the light emitted from the diode varies with the wavelength in the manner shown in Figure 2b. The dashed line in the figure designates the intensity curve for the light from the active layer 2, which corresponds to the intensity curve for a known LED of the kind described with reference to Figure 1. As will be clear from Figure 2b, in an LED according to the invention a considerably larger spectral line width is obtained that in prior art LEDs.

The magnitude of the intensity of the two intensity peaks of the curve in Figure 2b may be influenced by the choice of the thickness of the layer L. In an LED of the above-described kind, for example, a thickness of the layer L of 1 μm has proved to result in about half of the light emitted from the layer 2 being absorbed in L and half of the light being transmitted through the layer L, which gives the curve shown in Figure 2b with approximately the same intensity of the two intensity peaks.

In the alternative embodiment of the invention shown in Figure 3a, the layer L1 corresponds to the layer L in Figure 2a. In addition, a second P-doped luminescence layer L2 has been arranged to the left of the layer 2. The layer L1 has

an energy gap E_{gL1} which is lower than the energy gap E_{gA} of the active layer 2. The second luminescence layer L2 has an energy gap E_{gL2} which is lower than the energy gap E_{gL1} of the layer L1. In the same way as described above with reference to Figure 2, light with an intensity maximum at the wavelength λ_A is emitted from the layer 2. About half of this light is emitted to the right in the figure and, in the manner described with reference to Figure 2, causes emission of light from the layer L1 with an intensity maximum at the wavelength λ_{L1}. About half of the light emitted from the layer 2 is emitted to the left in the figure and in the same way excites charge carriers in the layer L2. Upon recombination of these charge carriers, light is emitted from the layer L2 with an intensity maximum at the wavelength λ_{L2}. By a suitable choice of the energy gaps of the layers 2, L1 and L2, the intensity curves of the light emitted from these layers may be caused to overlap and provide a resultant intensity curve with the appearance shown in Figure 3b. As will be clear from this figure, an even larger increase of the total spectral line width may be obtained in this way. In a typical LED of this kind, a line width of about 120 nm may be obtained.

In the same way as described above with reference to Figure 2, the intensity of the light emitted from the layers L1 and L2 may be controlled by the choice of the thicknesses of these layers.

Figure 4 shows an additional embodiment of an LED according to the invention. In this, an N-doped blocking layer B1 has been arranged between the layer L1 and the exit surface 7, and a second blocking layer B2 has been arranged to the left of the layer L2. The layer B2 is P-doped. The layers B1 and B2 are made of material with a higher energy gap E_{gB} than that of the active layer, for example with approximately the same energy gap as that of layers 1 and 3. The blocking layers B1 and B2 cause charge carriers to be retained in the luminescence layers, whereby an increased re-

lative intensity of the light emitted from these layers is obtained.

The above embodiments of the invention describe the invention applied to an LED with a double heterostructure, that is, with two heterojunctions (junctions between materials with different energy gaps). Figure 5 shows how the invention may be applied also to an LED with a single heterostructure, that is, with one single heterojunction. The LED may then consist of a P-doped layer 2, which constitutes the active layer of the diode and has the energy gap E_{gA}. Further, the diode has an N-doped layer 3 with a higher energy gap than that of the layer 2, and between the layers 2 and 3 the PN junction of the diode is produced. A luminescence layer according to the invention is arranged between the layer 3 and the exit surface 7 of the diode. The function of the luminescence layer will be the same as that described above, for example with reference to Figure 2. Alternatively, as described with reference to Figures 3, 4, 7, 8, one or several additional luminescence layers may be arranged and, further, blocking layers according to Figures 4, 7, 8 may be arranged on one or both sides of the structure shown in Figure 5.

As an alternative, Figure 6 shows how the invention may be applied to an LED with a so-called homostructure, that is, a diode in which the layers on both sides of the PN junction of the diode have approximately the same energy gap. The layer 2 in the figure is P-doped and the layer 3 N-doped, and both layers have the energy gap E_{gA}. Between the layer 3 and the exit surface 7 of the diode, a luminescence layer L is arranged. In the same way as mentioned above with reference to Figure 5, the diode may be provided with additional luminescence layers, as well as with one or more blocking layers.

Figure 7 shows yet another embodiment of an LED according to the invention. Compared with the diode shown in Figure 4, a

third luminescence layer L3 and a third blocking layer B3 have been added between the layer B1 and the exit surface 7. The material in the layer L3 has an energy gap E_{gL3} which is lower than E_{gA} but higher than E_{gL1} and E_{gL2}. Light will be generated also in the luminescence layer L3 and with a wavelength which is different from the wavelength of the light from the active layer 2 and the two blocking layers L1 and L2. In this way, an additional increase may be obtained of the spectral line width of the diode, and it has been found that a line width of about 150 nm may be obtained.

Figure 8 shows a section through an LED according to Figure 7. The figure schematically shows how the light emitted from the diode is composed of four components. A first component consist of the light emitted directly from the active layer 2 with an intensity maximum at the wavelength λ_A. Part of the light from the layer 2 is absorbed in the layer L1 and causes emission from this layer of light with an intensity maximum at the wavelength λ_{L1}. An additional part of the light from the layer 2 is absorbed in the layer L2 and causes emission from this layer of light with an intensity maximum at the wavelength λ_{L2}. Yet another part of the light from the active layer 2 is absorbed in the layer L3 and causes emission from this layer of light with an intensity maximum at the wavelength λ_{L3}. To the right of the structure shown in Figure 8, an additional layer corresponding to the layer 4 in Figure 1a may be arranged.

As mentioned above, the LED may be made from GaAlAs, but other materials may, of course, be used, for example InGaAsP. Further, it has been described above how the layers located to the left of the PN junction 6 in the figures are P-doped and how the layers located to the right of the junction are N-doped. The doping types may, of course, be the opposite. In the foregoing description, the concept "light" has been used, by which concept is meant electromagnetic radiation both within the visible wavelength band and within adjacent wavelength bands. The well located

centrally in the layer 4 in Figure 1 may be omitted and, as is shown in Figure 8, this is also true of the layer 4 in its entirety. An LED according to the invention may, of course, contain other semiconductor layers in addition to the layers shown in the above figures.

CLAIMS

1. A surface emitting light emitting diode with at least one PN junction (6) between two semiconductor layers (2, 3), at least one (2) of which is active, said diode being adapted to emit light through a predetermined exit surface (7), **characterized in that** the diode comprises at least one additional layer (L), a luminescence layer, which is made of a material with a lower energy gap (E_{gL}) than that of the active layer (E_{gA}) and is arranged between the active layer (2) and the exit surface (7).

2. A surface emitting LED according to claim 1, which has a double heterostructure with a first layer (1) of a first conduction type (P), a second layer (2) of said first conduction type (P) arranged adjacent to said first layer and between said layer and the exit surface (7) and constituting the active layer, a third layer (3) of a second conduction type (N) arranged adjacent to said second layer (2) and between said layer and the exit surface (7), said first and third layers being made of a material with a higher energy gap (E_{g1}, E_{g3}) than the material of the second layer (E_{gA}), **characterized in that** a luminescence layer with a lower energy gap (E_{gL}) than that of the second layer (E_{gA}) is arranged between said third layer (3) and the exit surface (7).

3. A surface emitting LED according to claim 1, which has a simple heterostructure with a first layer (2) of a first conduction type (P), which constitutes the active layer, a second layer (3) of the opposite conduction type (N) arranged adjacent to the first layer and between said layer and the exit surface (7), said second layer (3) being made of a material with a higher energy gap (E_{g3}) than the material in the first layer (2; E_{gA}), **characterized in that** a luminescence layer (L) with a lower energy gap (E_{gL}) than that of said first layer (E_{gA}) is arranged between said second layer (3) and the exit surface (7).

4. A surface emitting LED according to claim 1, which has a monostructure with a first layer (2) of a first conduction type (P) and a second layer (3) of the opposite conduction type (N) arranged adjacent to said first layer and between said layer and the exit surface (7), at least one of said layers (2) constituting an active layer, the materials in the two layers having substantially equally large energy gaps (E_{gA}), **characterized in that** a luminescence layer with a lower energy gap (E_{gL}) than said first and second layers is arranged between said second layer (3) and the exit surface (7).

5. A surface emitting LED according to any of claims 1-4, **characterized in that** it has two luminescence layers (L1, L2) arranged on both sides of the active layer (2), namely a first luminescence layer (L1) arranged between the active layer (2) and the exit surface (7) and a second luminescence layer (L2) on the opposite side of the active layer, the materials in the two luminescence layers having lower energy gaps (E_{gL1}, E_{gL2}) than the material in the active layer (E_{gA}).

6. A surface emitting LED according to claim 5, **characterized in that** the materials in the two luminescence layers have energy gaps (E_{gL1}, E_{gL2}) of different magnitudes.

7. A surface emitting LED according to claim 6, **characterized in that** the second luminescence layer (L2) has a lower energy gap (E_{gL2}) than the first luminescence layer (E_{gL1}).

8. A surface emitting LED according to any of claims 5-7, **characterized in that** it has a third luminescence layer (L3) arranged between the first luminescence layer (L1) and the exit surface (7), the material in the third luminescence layer having a lower energy gap (E_{gL3}) than the material in the active layer (2; E_{gA}).

9. A surface emitting LED according to claim 8, **characterized in that** the material in the third luminescence layer (L3) has a higher energy gap (E_{gL3}) than the material in the first (L1) and second (L2) luminescence layers.

10. A surface emitting LED according to any of claims 1-9, **characterized in that** it comprises a blocking layer (B1) with a material with a higher energy gap (E_{gB}) than the material in a luminescence layer (E_{gL1}) and arranged adjacent to the luminescence layer (L1) and on the opposite side thereof in relation to the active layer (2).

11. A surface emitting LED according to claim 10, **characterized in that** it comprises a first blocking layer (B1) with a higher energy gap (E_{gB}) than that of the first luminescence layer ((E_{gL1}) and arranged adjacent to said layer and between said layer and the exit surface (7), and a second blocking layer (B2) with a higher energy gap (E_{gB}) than that of the second luminescence layer (E_{gL2}) and arranged adjacent thereto and on the opposite side thereof in relation to the active layer (2).

Fig. 1a

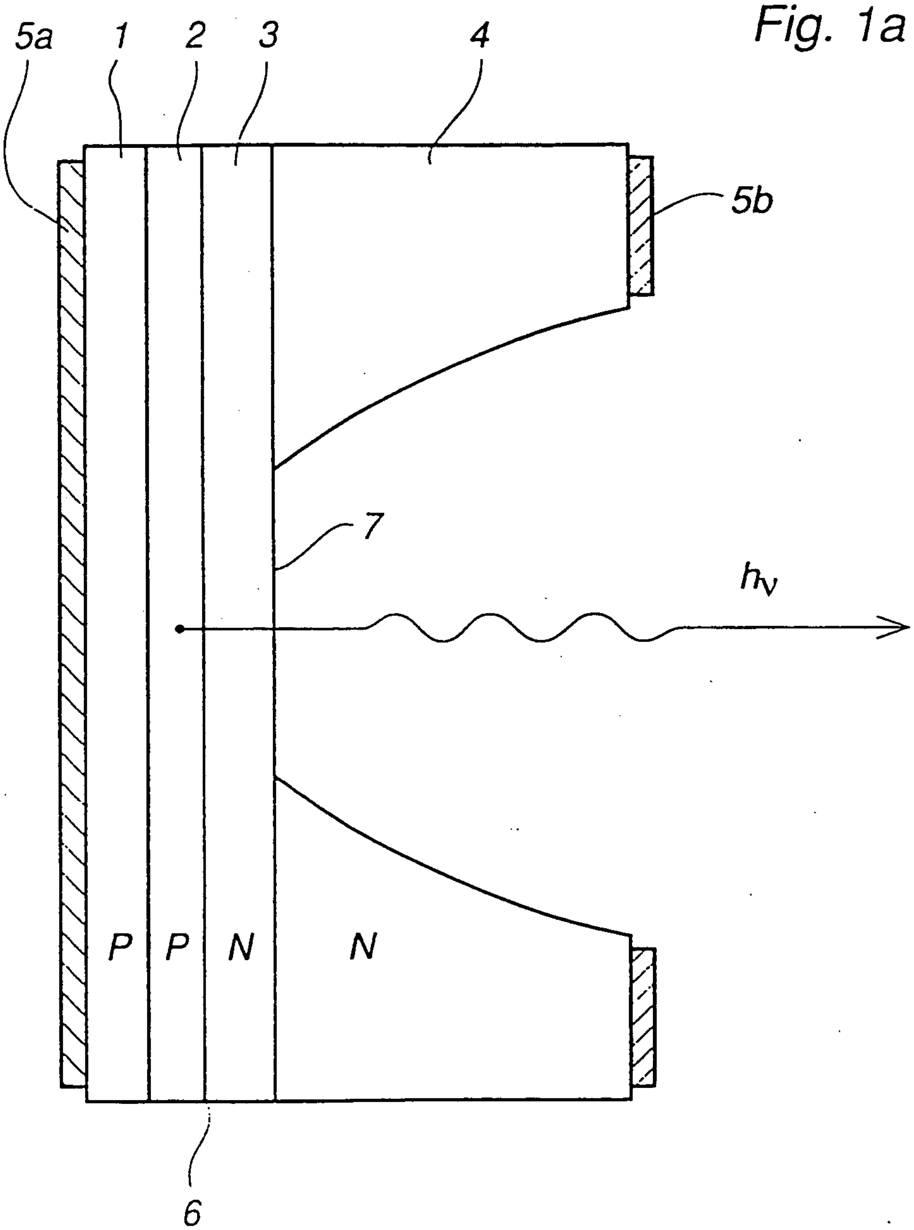


Fig. 1b

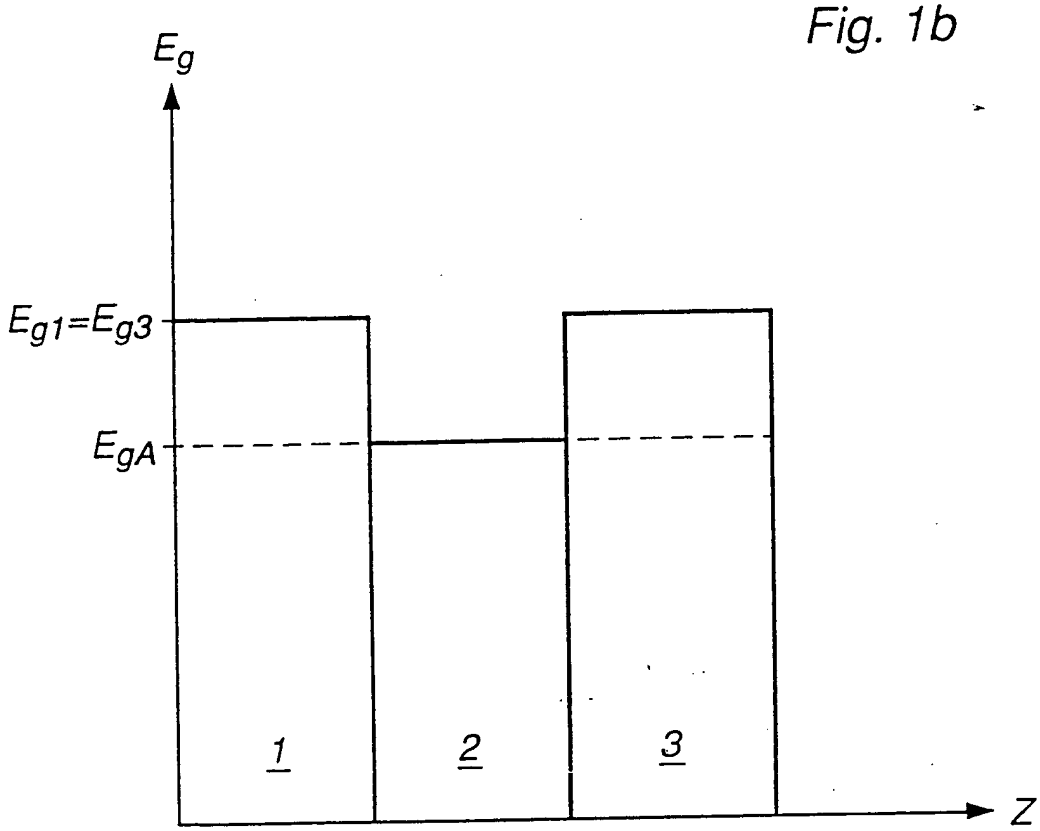


Fig. 1c

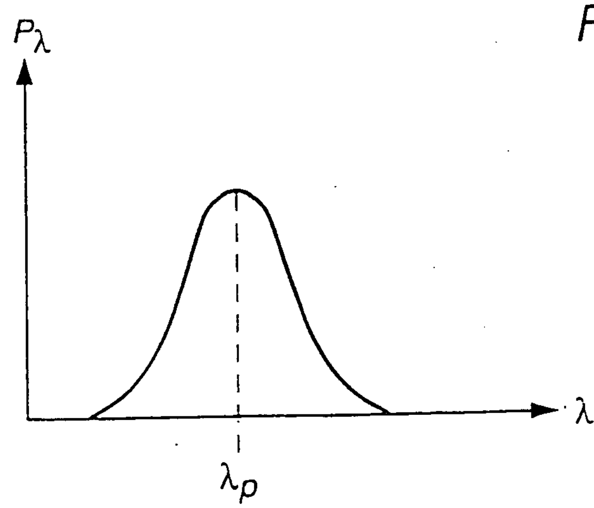
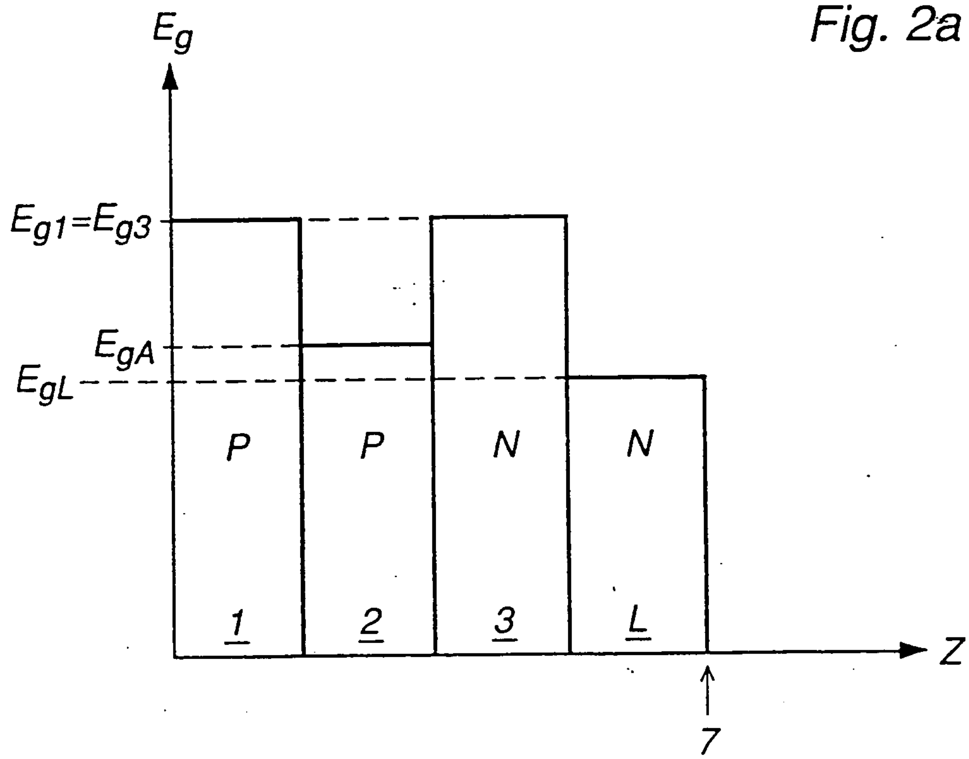


Fig. 2a


E_g
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E_{gA}
E_{gL}
P
P
N
N
1
2
3
L
Z
7

Fig. 2b

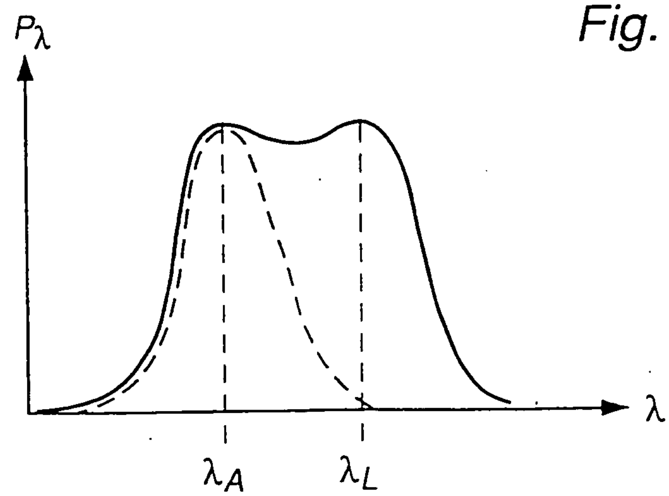
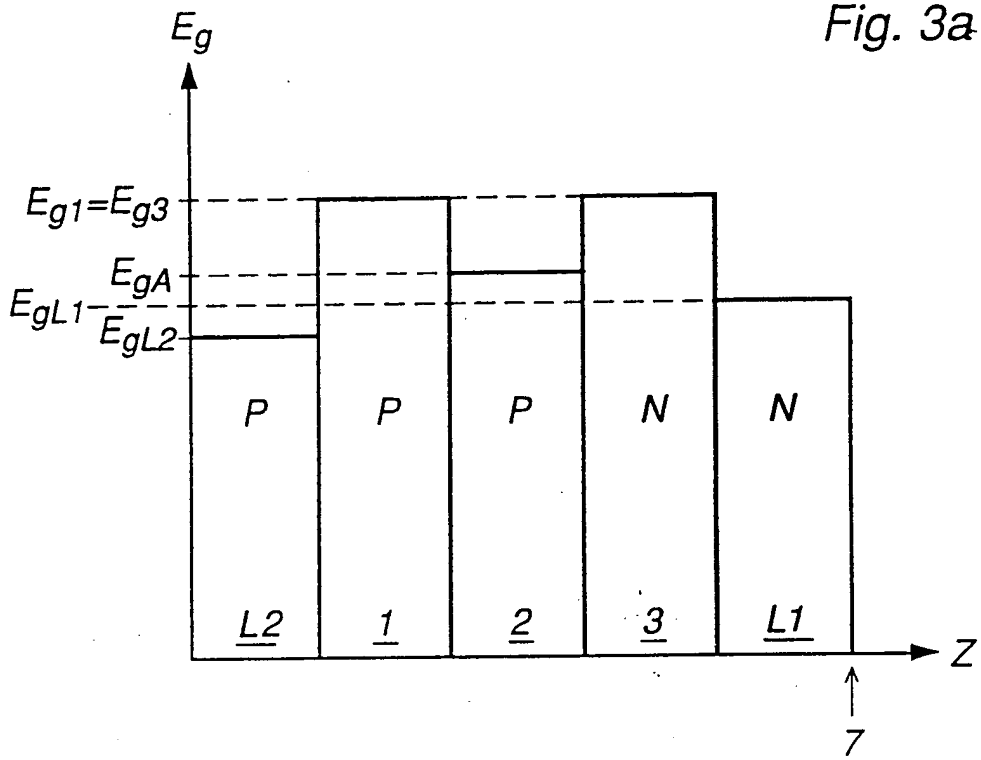

P_λ
λ
λ_A
λ_L

Fig. 3a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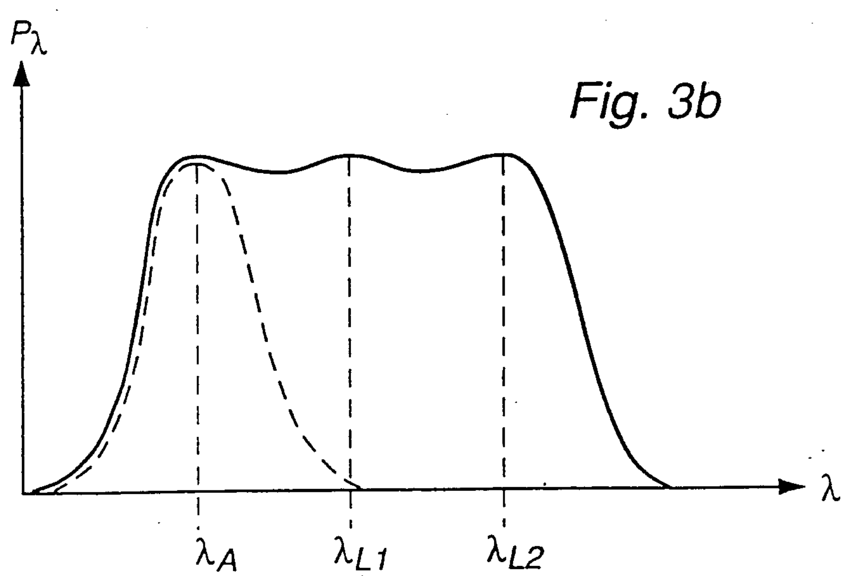
P
P
P
N
N
L2
1
2
3
L1
Z
7

Fig. 3b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λ_{L1}
λ_{L2}

Fig. 4

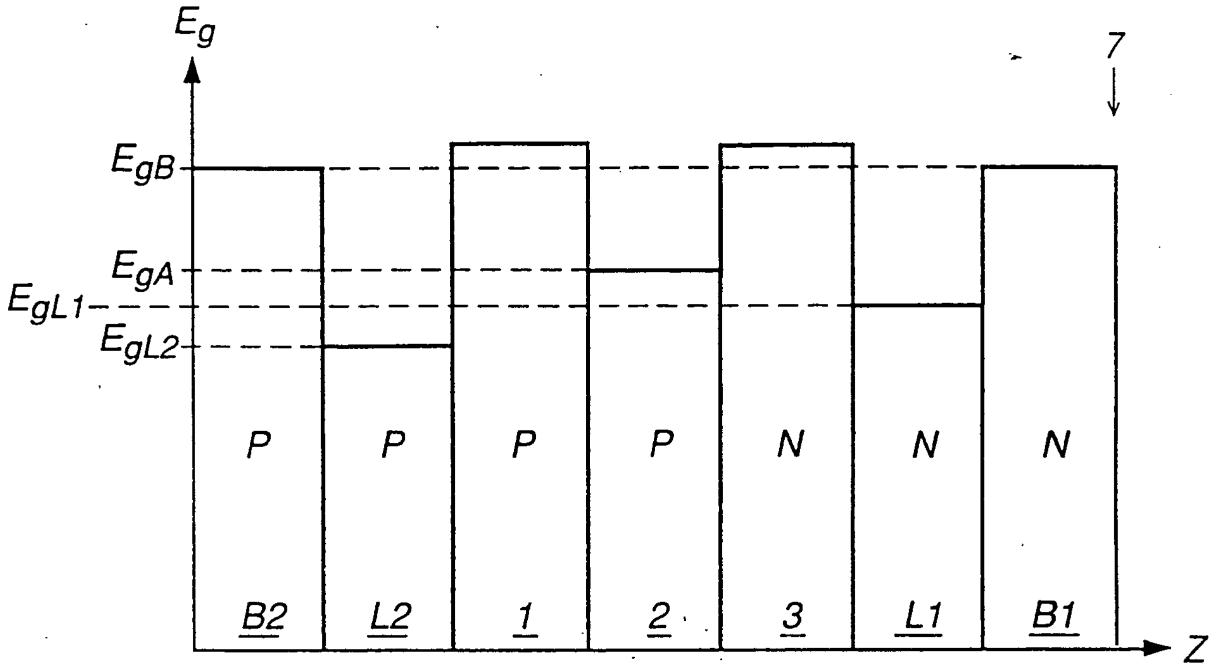
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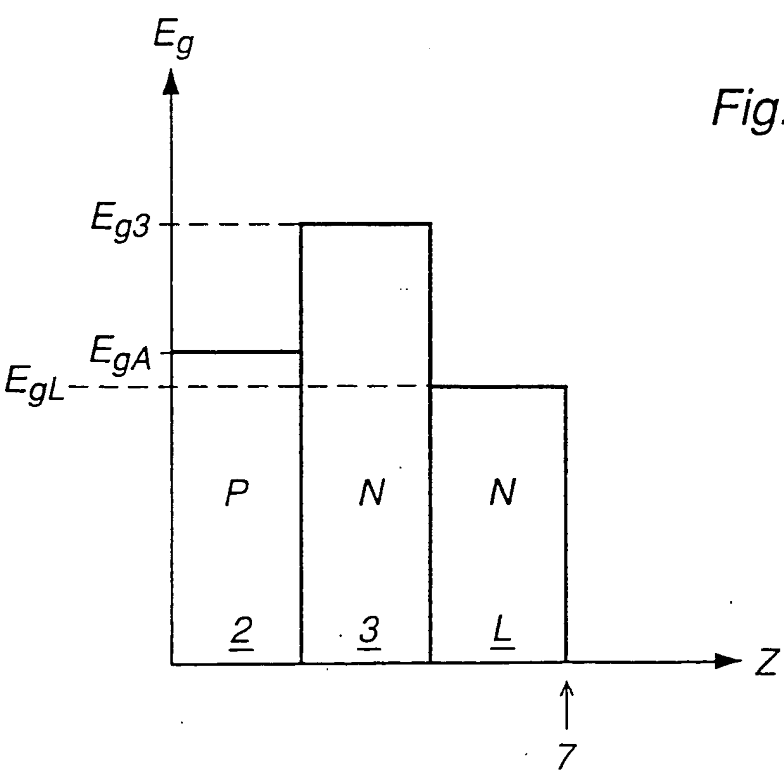
Fig. 5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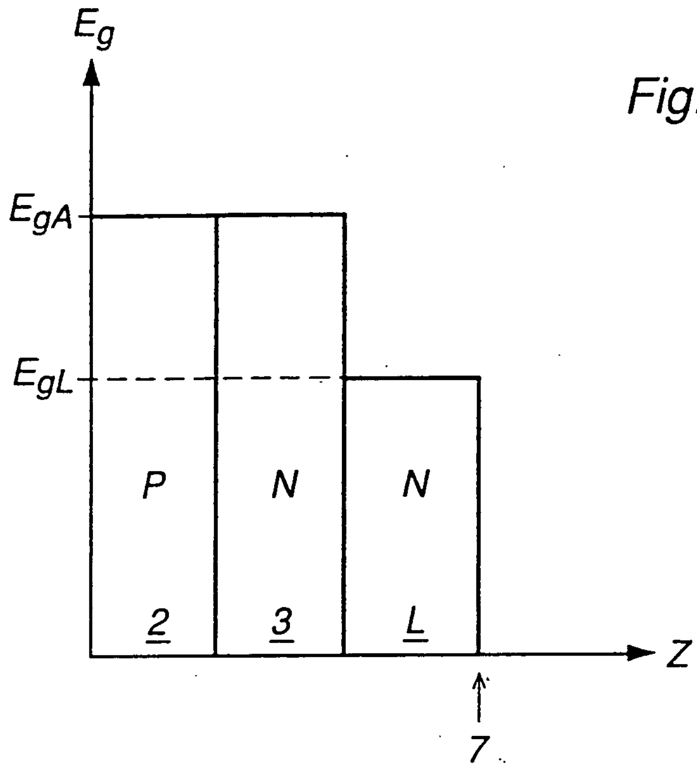

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3
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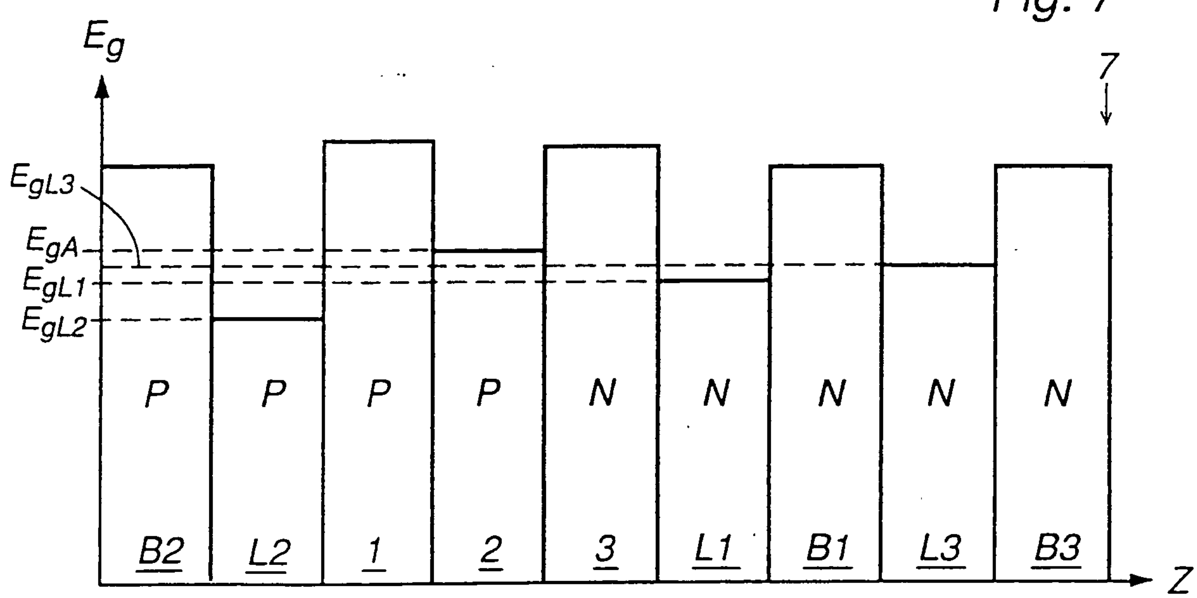
Fig. 6



7
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E_{gA}
E_{gL1}
E_{gL2}
P
P
P
P
N
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N
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N
B2
L2
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2
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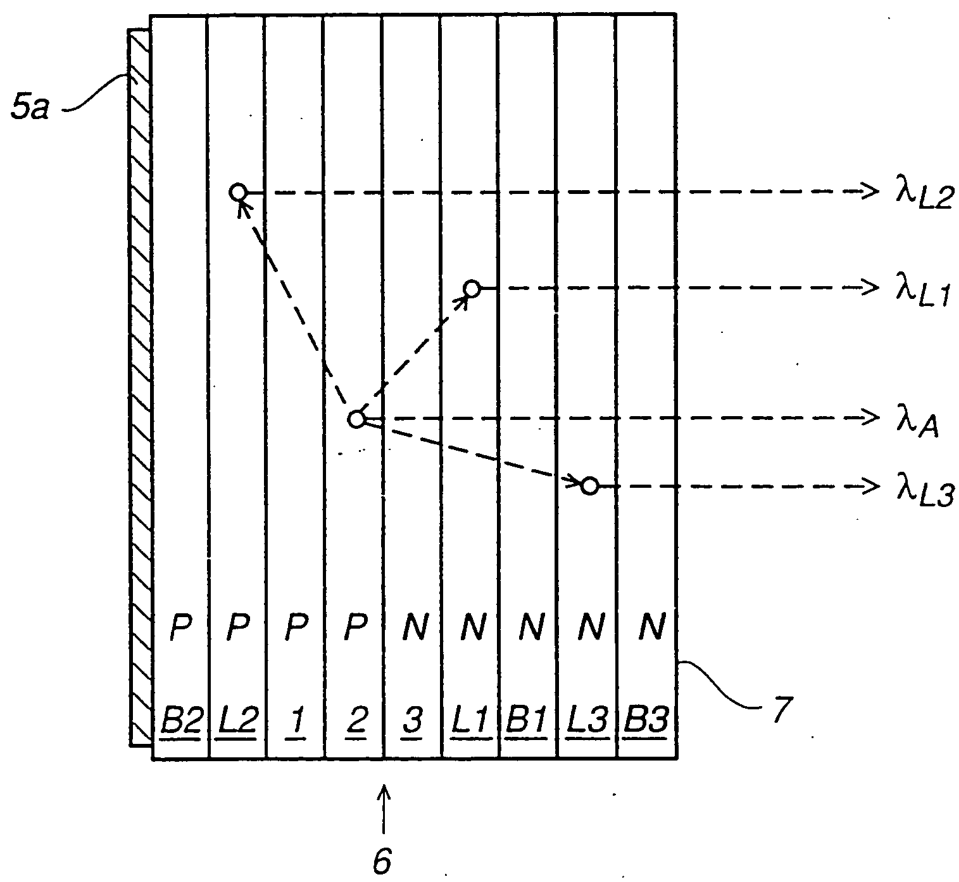
L1
B1
L3
B3
Z

Fig. 7

Fig. 8



INTERNATIONAL SEARCH REPORT

International Application No PCT/SE 92/00210

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC5: H 01 L 33/00

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
IPC5	H 01 L

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in Fields Searched[8]

SE,DK,FI,NO classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category *	Citation of Document,[11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
A	US, A, 4570172 (RAYMOND HENRY ET AL) 11 February 1986, see column 3, line 58 - column 4, line 16 --	1-11
A	WO, A1, 8200921 (WESTERN ELECTRIC COMPANY, INC.) 18 March 1982, see abstract --	1-11

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
7th August 1992	1992 -08- 17
International Searching Authority	**Signature of Authorized Officer**
SWEDISH PATENT OFFICE	Lars Jakobsson LARS JAKOBSSON

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO.PCT/SE 92/00210

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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4570172	86-02-11	DE-A- 3373956	87-11-05
		EP-A-B- 0114548	84-08-01
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		JP-A- 59121887	84-07-14
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		EP-A- 0059732	82-09-15
		US-A- 4374390	83-02-15

Docket # 1999 P 8006
Applic. # 09/915,985
Applicant: Hammel et al

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